PENNSTATE ARL

iMAST

Institute for Manufacturing and Sustainment Technologies

QUARTERLY 1999 No.1

Mr. George Singley (center), President, Hicks & Associates, listens to Mr. Al Lemanski (right) describe characteristics of new 3.5-inch Testek gear rigs that are now on-line at ARL. Mr. Lewis Watt (left), deputy director of iMAST looks on.

ARL's refurbished four-square 6-inch gear test rig, previously donated by Sikorsky Aircraft Company, joins fleet of test equipment available at ARL. ARL boasts one of the most comprehensive test facilities for gear and gear materials testing and measuring in the country.

FOCUS ON MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES

A U.S. Navy Manufacturing Technology Center of Excellence

High-Speed Power Circulating Gear Test Rigs Operational at ARL

New 3.5-inch center distance, high-speed, power circulating (four square) gear test rigs have been acquired and are now operational at Penn State's Applied Research Laboratory. The test rigs will support Navy ManTech gear tooth durability evaluation efforts associated with the ausform finishing process effort as well as other ongoing Navy and Marine Corps gear durability programs relative to high-performance transmissions.

iMAST's mechanical drive transmission technology thrust, also known as the Drivetrain Technology Center (DTC), will be implementing advancements in transmission technology to industry in support of the Navy and Marine Corps, Department of Defense, and the U.S. transportation sector.

The two new high-speed gear test rigs, capable of operating at 10,000 revolutions per minute, were manufactured by Testek, Inc. (Livonia, Michigan). The test rigs conform to stringent and critical specification standards written by the DTC. These standards include AGMA class 14 slave gears and a design that essentially eliminates the influence of dynamic loads on test gears that are inherent by-products of inaccurate slave gears used in four-square test rig design. The test gear box also has an independent lubrication system to allow gear testing with various lubricants at different temperatures. The loading mechanism has the capacity to generate the necessary gear tooth stresses for failure, even when the meshing test gear teeth are under full face-width contact.

With the addition of these two test rigs to existing test capabilities that include a 150 HP, four square 6-inch test rig, iMAST's Drivetrain Technology Center at ARL Penn State boasts one of the most comprehensive test facilities for gear and gear materials testing and measuring in the country. This test capability is available to the Navy and Marine Corps, to the Department of Defense, and to industry. Plans are also under way to procure a bevel gear test capability in the near future. For more information about this program, contact Mr. Al Lemanski at (814) 863-4481, or by e-mail at: ajl3@psu.edu

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **iMAST Quarterly, 1999 Number 1**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Penn State University,Applied Research Laboratory,Institute for Manufacturing and Sustainment Technologies,State College,PA,16804**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

PENNSTATE

iMAST

Applied Research Laboratory
Institute for Manufacturing and Sustainment Technologies

DIRECTOR
Henry E. Watson
(814) 865-6345 hew2@psu.edu

THRUST LEADER
Mechanical Drive Transmission Technologies
Alphonse J. Lemanski
(814) 863-4481 ajl3@psu.edu

THRUST LEADER
Materials Science Technologies
Maurice F. Amateau, Ph.D.
(814) 863-4481 mfa1@psu.edu

THRUST LEADER
High-Energy Processing Technologies
J. Thomas Schriempf, Ph.D.
(814) 863-9912 jts6@psu.edu

THRUST LEADER
Navy/Marine Corps Repair Technologies
Lewis C. Watt
(814) 863-3880
lcw2@psu.edu

iMAST ADMINISTRATOR and EDITOR
Gregory J. Johnson
(814) 865-8207 gjj1@psu.edu

STAFF ASSISTANT
Carol Ott
(814) 863-3207 (814) 863-1183 FAX
cvo1@psu.edu

WORLD WIDE WEB
www.arl.psu.edu/core/imast/imast.html

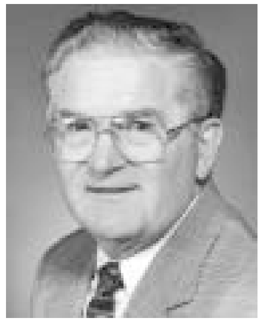
NAVY PROGRAM MANAGER
Ted Hicks
(215) 697-9528 hickst@onr.navy.mil

IN THIS QUARTERLY

DIRECTOR'S CORNER

Changes on the Horizon

This month we are featuring the Drivetrain Technology Center. As with many of our organizations, changes are on the horizon. Suren Rao has decided to end his tenure as head of the Drivetrain Center and to focus his ARL activities on the Gear Research Institute as its respective director. He will also manage selected Navy ManTech projects that are Drivetrain Center-related. This action is effective April 1, 1999. A search is underway for his replacement as Head of the Drivetrain Technology Center.



Speaking of changes, Ted Hicks is now the Office of Naval Research program officer for iMAST. Ted has been working as the program officer for the Repair Technology (REPTECH) effort for several years. As you may recall from our last quarterly, the REPTECH program is now a regular component of iMAST. Ted Hicks replaces Leo Plonsky, who supported ARL as the Manufacturing Science and Advanced Materials Processing Institute (MS&AMPI) program officer, the predecessor to iMAST. Leo was a tireless and very effective worker in providing oversight and direction to our ONR-funded Navy ManTech projects. Leo now goes on to bigger challenges with the MARITECH program, which was also discussed in our last quarterly.

Ted Hicks is an experienced program officer. As you may know, he is already responsible for two other Navy ManTech Centers of Excellence in addition to our own.

iMAST is managed by ARL's Office of Materials and Manufacturing Technology. Continuing with the theme of change, the Office of Materials and Manufacturing Technology was assigned the responsibility, through a cooperative agreement, to operate the Electro-Optics Center (E-O Center) for the Manufacturing Technology Division of ONR. The agreement was signed on February 25 for five years with a funding limit of $25M. We are currently in the process of spooling up the center and establishing the technology program that will be funded during the first year.

The E-O Center is supported by an alliance of industry partners, academia, and government affiliates.

If you have any questions about any of the matters above, or about items in this quarterly, please give me a call (814) 865-6345 or contact me via e-mail at: hew2@psu.edu

As always, I will look forward to hearing from you.

Henry Watson

PENNSTATE iMAST

MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES | MATERIALS SCIENCE TECHNOLOGIES | HIGH-ENERGY PROCESSING TECHNOLOGIES | NAVY/MARINE CORPS REPAIR TECHNOLOGIES

Focus on Mechanical Drive Transmission Technologies

Ausform Finishing for Bulk Strength and Ductility

by Vince Delbrugge, Ph. D.

An extensive ausform finishing process developmental program has been under way at Penn State's Applied Research Laboratory for several years now as part of its mechanical drive transmission technology effort. The principal focus of this effort has been towards developing an ausform finishing process to strengthen machine components for wear and contact fatigue resistance. This particular process typically limits plastic deformation of the marquenched, metastable, austenite to within 0.4mm of the surface. ARL's Institute for Manufacturing and Sustainment Technologies (iMAST) is currently in the second phase of a three-phase program focusing on the enhancement of high-performance gears and bearings for use in rotorcraft, ground combat, and ground combat service support vehicles.

Ausforming was initially developed as a bulk deformation process. To that end, iMAST has recently begun a joint project with the Army's Tank Automotive Command (TACOM) to bulk ausform a ferrous casting alloy that will be used as material for a component on a track-wheeled vehicle. The ductile cast iron will be austempered after ausforming, rather than quenched and tempered like most ausform finished steels. Application will be on a track center guide. The cast alloy being considered has a 10 percent lower density than the steel currently being used which will significantly reduce weight but retain acceptable strength.

Implications of bulk ausforming are numerous. Beyond providing performance enhancements, fuel efficiency, and lower life-cycle costs, bulk ausforming ductile iron provides an up-front, lower-cost opportunity to eliminate more expensive end-line weight reduction initiatives.

Ductile cast iron is distinct from other cast irons in that its graphite phase exists as distinct spheroids. This significantly improves its mechanical properties over those of other cast irons, which have graphite plates that extend over large volumes of the alloy. Thus, ductile iron is often considered as a composite silicon steel matrix with about 12–15 percent voids by volume. While this assumption has some validity for mechanical properties, the graphite has important influences on the response to thermal processing. Ausforming has proven to be instrumental in producing optimal mechanical properties in this material, which has potential to replace steel in many applications.

The economic advantages of near-net-shape processing can be realized by casting; ausforming can be used to provide required performance capability. The role of iMAST's mechanical drive transmission thrust effort in the ausformed, austempered ductile iron (ADI) project is to model the response of a ductile iron during ausforming to finish the material to dimensional specifications, and obtain a specified amount of plastic strain in the metastable austenite.

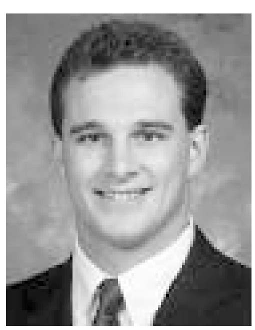
This article will describe the influence of austempering and ausform finishing on ductile iron. A review of the work to support the application of this material at TACOM is included.

ADI Overview

The thermal strengthening process of austempering begins by heating a ferrous alloy to form a microstructure of austenite and graphite. Austempering is quenching and maintaining a temperature above that for the start of martensite nucleation and below the temperature for diffusional transformation to ferrite and iron carbide. Maintaining the temperature of the ductile iron in this range results in a microstructure of fine ferrite plates or sheaves, and austenite, with fine iron carbide also forming at lower austempering temperatures that approach those for martensite nucleation and growth.

The alloy content and graphite constituent of ductile iron make ADI microstructures more desirable than quenched and tempered structures for ductile iron applications requiring strength. Research shows that tempering martensitic ductile iron results in formation of more graphite nodules due to diffusion of the interstitial carbon

PROFILE



Vincent Delbrugge, is a research engineer with the Drivetrain Technology Center at ARL Penn State. He has been with ARL since 1999. A Ph.D. graduate from Penn State in Engineering Science and Mechanics, Dr. DelBrugge's work includes finite element analysis and micromechanics to predict the final dimensions and residual stress tensor in ferrous alloys processed by carburizing, quenching, and tempering treatments, as well as surface rolling.

Dr. Delbrugge's responsibilities include tool and automation design as well as operation of ausform finishing hardware for the Drivetrain Technology Center's ausform finishing process program headed up by Nagesh Sonti, Ph.D. Other responsibilities include the material characterization effort by metallography and electron microscopy, and X-ray diffraction.

Dr. Delbrugge can be reached by calling (814) 865-4367 or by e-mail at: gvd100@psu.edu

CONTINUED FROM PAGE 3

atoms from the untempered martensite, which decrease both fracture toughness and yield strength.

Retained austenite is often considered detrimental to applications involving cyclic loading. However, morphology and interstitial carbon content of this phase actually dictate its influence on performance.

The graphite nodules in ductile iron are both a source and sink for carbon atoms. As the alloy is heated into the austenite range, the solubility limit for carbon in the austenite, $\%C_\gamma$, increases with austenitizing temperature, T_γ.

$$\%C_\gamma = \frac{T_\gamma(°C)}{420} - 0.17(\%C) - 0.95 \text{ weight\%}$$

Figure 1 illustrates the iron-carbon phase diagram sectioned at 2 percent silicon. This figure shows how the carbon content increases with temperature in the austenitic temperature range when the bulk carbon is in excess of 2 percent. Note that this relationship does not exist for carbon steels. The figure also illustrates the relatively lower melting temperature of the cast irons, and graphite, not iron carbide, as the equilibrium constituent.

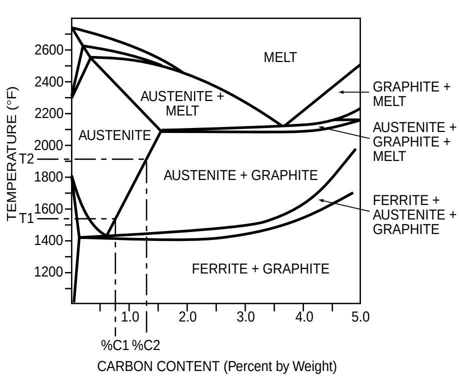


Figure 1. Iron-carbon phase diagram sectioned at 2 percent silicon.

The austenite that is retained in ADI after quenching to room temperature can have interstitial carbon approaching 2 percent. This unusually high level of carbon is possible because the transformation of austenite to ferrite is accompanied by further diffusion of the carbon into the austenite.[6] A condition of meta-stable equilibrium can be reached such that the austenite is thermodynamically stable, and enhances mechanical properties of the ADI.

Increasing the fraction of austenitic interstitial carbon increases the yield strength of the constituent by impeding slip of the close-packed planes in the face- centered structure. This strength increase is of the magnitude that twinning becomes a more common mode of deformation relative to slip in the austenite.[7] Deformation twins are not typical in face-centered cubic structures.

The amount of time for austempering is approximately the same as that required for tempering a martensitic alloy. Although the mechanisms controlling nucleation and growth of the constituents in ADI are debated, there is evidence of both shear and diffusion. Diffusion, of course, dictates the time required for transformation, and the transformation is adequately modeled using the Avrami relationship.[5]

Substitutional alloy segregation, typical in cast alloys, adversely influences diffusivity of the carbon. Segregation can result in large austenite constituents that are proportional in size to the primary solidification cells after austempering. These cells are the morphological equivalent of grains in wrought alloys. This large austenite morphology with its low carbon content has proven to be detrimental to mechanical properties of the casting.[3,8]

Ausform Finishing

Independent of alloy content, carbon diffusivity in either austenite or ferrite is also influenced by constituent size and dislocation density. In general, increasing dislocation density, and decreasing constituent size both increase diffusivity by orders of magnitude over diffusivity of continuous lattice structures. Immobile dislocations and phase boundaries are also favorable nucleation sites for new phases.[4]

A process that exploits these mechanisms is ausforming, plastic deformation of metastable austenite. Typically performed before quenching to martensite, Moore[3] and Yamada[8] have demonstrated its applicability to ADI. The equivalent plastic strain in the austenite is increased; the microstructural effects of this strain increase are persistent during and after austempering.[3] Figure 2 illustrates the ausforming process superimposed on the Time-Temperature-Transformation diagram for an iron-carbon alloy. Despite microstructure similarities, austempered steel has traditionally been called Bainite, while austempered ductile is typically identified by its process acronym ADI.

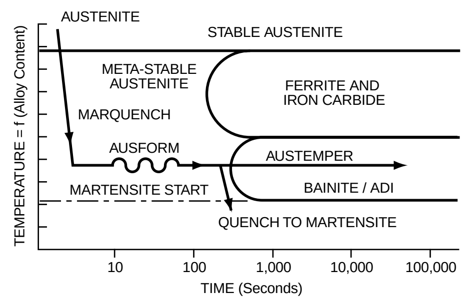


Figure 2. Ausform process superimposed on the time–temperature–transformation diagram for an iron–carbon alloy.

Increased dislocation density and grain refinement increase the number of dislocation sites for the ferrite sheaves/plates to begin growing during austempering, and increase the rate of diffusion of carbon to the austenite. At lower austempering temperatures, the iron carbide phase distribution is further refined due to the increase in diffusivity.

The ferrite constituents in the austempered structure inherit the work hardening effects from the austenite. Yield strength of the ductile iron is increased with the increase of immobile dislocation density, the Hall-Petch relationship, and interstitial strengthening mechanisms after ausforming.

Fracture toughness and ductility are also increased by ausforming ADI. These improvements are both partially attributed to minimizing the volume of retained austenite at the center of the primary solidification cell, which has been correlated with decreased resistance to crack propagation. The effects of ausforming increase the free energy available for the transformation to the ferrite constituent in this alloy-segregated region.

Ausform finished steels typically respond to ausforming with a 20 percent increase in yield strength and a tenfold increase in resistance to contact fatigue failure[1]. A similar mechanical response has been achieved in ausform finished ADI.[3,8]

Modeling Ausform Finishing

The centerguide, a component on a tracked vehicle that is currently made from a steel forging, has been selected as a candidate component for replacement with ausformed ADI material. The centerguide has several geometric features that are not significantly loaded in service. Therefore, a part with similar but simplified geometry, called a “wear specimen,” is being used for initial manufacturing simulation and performance testing, before the complete centerguide geometry is ausformed.

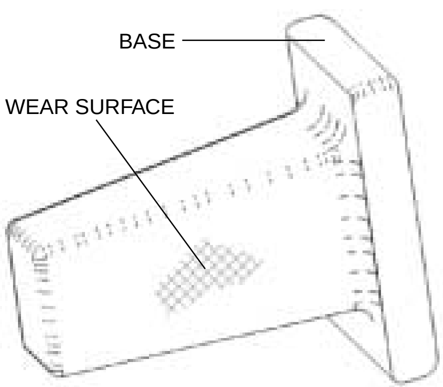


Figure 3. Wear specimen geometry.

The wear specimen final geometry is illustrated in Figure 3. One of the main criteria in determining the applicability of ausformed ADI to a component such as the centerguide will be the difference in performance of an ausformed ADI wear specimen and an ADI specimen processed without ausforming. Using the stress-strain relationship shown in Figure 4, the as-cast geometry of the specimen for ausforming has been determined with a numerical model, which was also used to design the ausforming specimen such that forging would result in approximately 20 percent equivalent plastic strain in the metastable austenite before austempering.

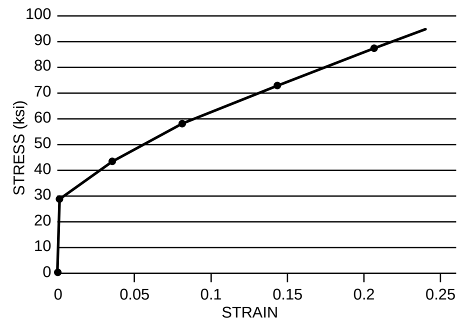


Figure 4. Stress strain relationship for meta-stable austenitic ductile iron after austenitizing and marchenching. The yield strength for the meta-stable austenite is much lower than the room temperature strength of the alloy after quenching, which is over 180 ksi.

The stress-strain relationship shown in Figure 4 was used with a rate-independent flow law to model the ausforming process. The representative volume element for the model was considered homogeneous and isotropic. Specifically, the graphite nodules were not discretized from the ferrous microstructure, nor was the response of any other microstructural constituent defined.

The “base” of the specimen illustrated in Figure 3 is not ausform finished. The hardware geometry for ausforming is illustrated in Figure 5. Additional assumptions exclude Coulomb’s general friction law between the dies and ductile iron, and temperature variation during deformation. Ductile yield criteria was that of von Mises, and the flow rule used was that developed by Prandtl and Reuss.

Initial modeling was performed on two-dimensional sections, but the final modeling for the wear specimen was performed with a quarter-section of a three-dimensional model. Figure 6 illustrates the mesh, constraints, and loading technique. Figure 7 illustrates the five locations where the specimen is virtually sectioned for strain mapping.

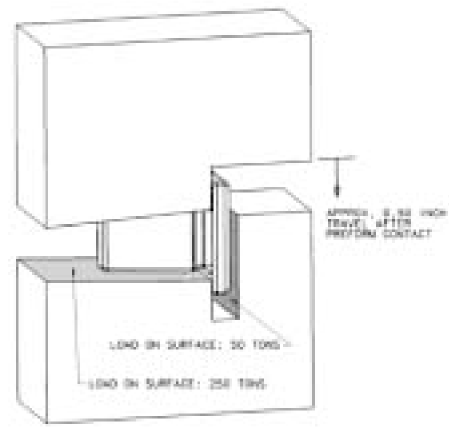


Figure 5. Hardware for ausforming, with preform specimen.

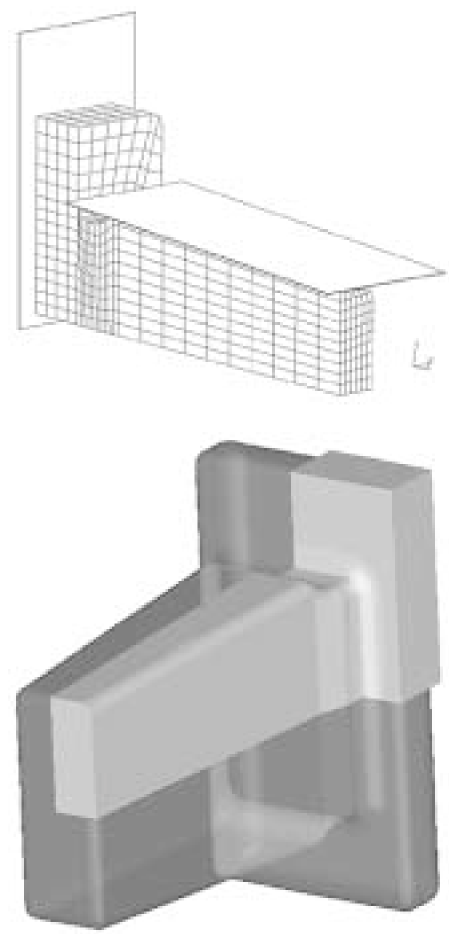


Figure 6. The quarter-section of preform for finite element modelling (bottom). Boundary conditions are illustrated at the top.

CONTINUED FROM PAGE 5

In addition to modeling for nominal geometry, tolerance was accounted for in both the geometry and stress-strain curve for force requirements in additional models. A spherical surface flaw was also modeled in several surfaces to determine its quantitative concentration of plastic strain.

The as-cast geometry for both the wear specimen and preforms are illustrated in Figure 8. The dimensional tolerances determined by the model were within those recommended for sand casting, and still permit the 20 percent equivalent plastic strain to be present after ausforming.

Current Status

The finite element model was used to develop drawings that commercial foundries are using for cost estimation and tool design.

Following delivery and quality assurance of the castings, the preform wear specimens will be ausform finished. Performance testing of the castings will then be performed by the sponsor. The same procedure will be followed for casting and ausforming the centerguide geometry. Secondary operations will be required to completely finish the centerguide, which requires drilled and reamed holes.

The ausform finishing efforts at ARL Penn State continues to be extensive. It remains a high-visibility program with the Navy, Marine Corps, and also the Army. As noted, the ausform finishing effort has the potential to significantly impact a unique number of manufacturing processes relative to the manufacture of mechanical drive transmission components. This includes system design acquisition, performance, and life-cycle costs.

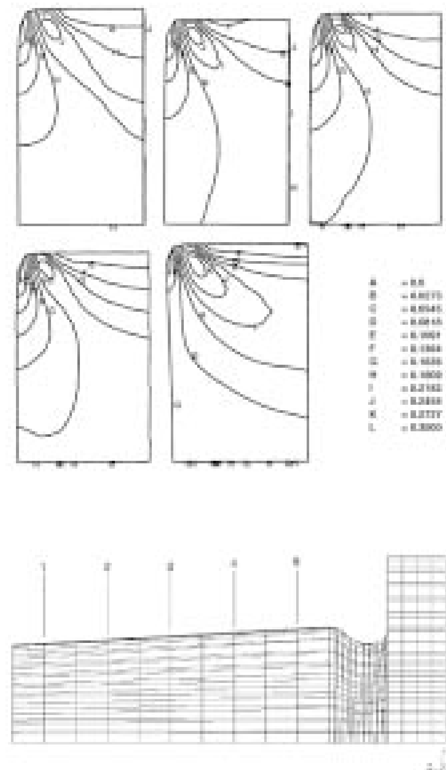


Figure 7. Locations for equivalent plastic strain mapping (bottom). Strain maps are shown at top.

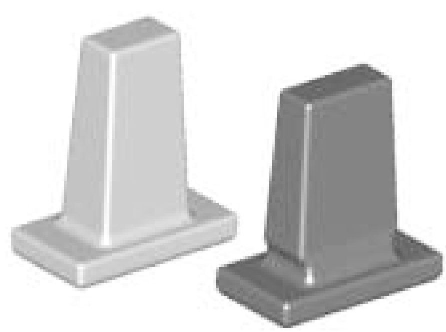


Figure 8. Wear specimen (left) and preform as-cast geometry.

Acknowledgment

The author is grateful for support from iMAST at ARL Penn State. iMAST is a nonprofit organization sponsored by the United States Navy Manufacturing Technology (ManTech) Program, Office of Naval Research (contract number N00039-97-D-0042). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the U.S. Navy.

References

1. Amateau, M.F., and Cellitti, R.A. “Finishing of Gears by Ausforming.” SME Technical Paper MF86-922, 1986.
2. Moore, D.J., Rouns, T.N., and Rundman, K.B. “The Effect of Heat Treatment, Mechanical Deformation, and Alloying Element Additions on the Rate of Bainite Formation in Austempered Ductile Irons.” *Journal of Heat Treating*, v4, n1, pps. 7-23.
3. Moore, D.J., Rouns, T.N., and Rundman, K.B. “Structure and Mechanical Properties of Austempered Ductile Iron.” *AFS Transactions*, 85-103, pps. 705-718.
4. Murch, G.E., and Nowick, A.S. *Diffusion in Crystalline Solids*. Orlando: Academic Press, Inc., 1984.
5. Rouns, T.N., and Rundman, K.B. “Constitution of Austemperd Ductile Iron and Kinetics of Austempering.” *AFS Transactions*, 87-116, pps. 851-859.
6. Rundman, K.B., and Klug, R.C. “An X-Ray and Metallographic Study of Austempered Ductile Iron.” *AFS Transactions*, v90, pps. 499-508, 1982.
7. Vuorinen, J.J. “Strain Hardening Mechanism and Characteristics of Austempered Ductile Iron.” *AFS Transactions*, 86-100, pps. 577-588.
8. Yamada, S., and Kobayashi, T. “Effect of Thermomechanical Treatment on Toughness of Spheroidal Graphite Cast Iron.” Symposium on the Physical Metalurgy of Cast Iron, Session 1, Nancy, France, October 3-5, 1994.

Mr. Art Linden (center right) and Mr. Steve Glusman (center left) pause for photo with research assistant Eric Whitney (far left), next to iMAST's 14-Kw CO_2 Laser Articulating Robotic System (LARS). At far right is Al Lemanski, acting director of ARL's Drivetrain Center.

Pausing for a photo next to iMAST's 1/12 scale MCB Barstow air treatment (paint booth exhaust) facility, located at ARL Penn State are (left to right) Colonel Larry Larson; Ms. Kim Weirick, Colonel Larson's deputy director; Mr. Craig Sakai, head, Environmental Management Program, HQMC; Mr. Lewis Watt, deputy director, iMAST; and Dr. Brad Streibig, research associate, ARL Penn State.

Comanche Program Director Visits iMAST

Mr. Arthur Linden, Boeing-Sikorsky Vice President and Program Director for the RAH-66 Comanche, visited the institute for a technology and capabilities overview. Accompanying Mr. Linden was Steve Glusman, RAH-66 Chief Engineer.

The U.S. Army's aviation modernization plan has, as its centerpiece, the Boeing-Sikorsky RAH-66 Comanche armed reconnaissance helicopter. The aviation plan reflects the Army's new post-Cold War strategy to react to regional conflicts by using fewer personnel and long-range, self-deployable aircraft based in the continental United States. The Comanche is a twin-turbine, two-seat (tandem) armed reconnaissance helicopter with projected missions of light attack and air combat. Initial operating capability is set for the year 2006.

Bearing Ausform Finishing Project Update

A meeting to kickoff a new project under the sponsorship of Navy ManTech was recently held between iMAST and its industrial partner. The objective of this project is to apply the ausform finishing process to rolling element bearings and to evaluate the enhancement of bearing durability due to the finishing process. Substantial tests on rolling-contact fatigue conducted at the Drivetrain Center have indicated an increase in bearing life of up to sevenfold. Alternatively, this translates to an approximate 50 percent increase in the load-carrying capacity of the bearing. This project is specifically targeted towards enhancing the load-carrying capacity of the transmissions on the Marine Corps' Advanced Amphibious Assault Vehicle (AAAV). The project sponsor is the DRPM AAAV office. All test bearings for ausform finishing and the actual durability testing of the bearings is being provided by the industry partner. Intellectual property agreements between Penn State and the industry partner are in place. For more information about this project, contact Dr. Nagesh Sonti at (814) 865-6283, or by e-mail at: nxs7@psu.edu

Watt Featured in Marine Corps Gazette

Lewis Watt, iMAST deputy director, recently had the article: "New Maintenance Technologies: Sustaining a 21st Century Marine Corps" published in the January issue of the Marine Corps Gazette. The Gazette is the professional journal of U.S. Marines. In the article, Mr. Watt addresses future maintenance challenges facing the Marine Corps and new potential solutions available for consideration. A complete copy of the article is available for reading on the iMAST web site under publications at the following address: http://www.arl.psu.edu/core/imast/publications.html

Marine Corps Installation and Logistics Team Visits

Colonel Larry Larson, director, Land Use and Military Construction Branch of Headquarters, U.S. Marine Corps, along with key members of his staff, recently visited iMAST as part of a capabilities review. Ongoing environmental efforts within the repair technology effort were the principal focus of the visit. The Marine Corps has established ambitious goals in all environmental areas. Their ultimate goal is to attain full and sustained environmental compliance and protection of natural, cultural, and historic resources. Many of the projects underway at iMAST address Marine Corps interests relative to their environmental mission goals. For more information on the Marine Corps' environmental effort, visit their environmental homepage on the World Wide Web at: http://www.hqmc.usmc.mil/enviro1/default.htm. For further information about iMAST's environmental efforts, please contact Robert Keay at (814) 865-7222 or by e-mail at: rek10@psu.edu

CALENDAR OF EVENTS

6–8 Apr	AW&ST Maintenance, Repair, and Overhaul ’99 Conference	Atlanta, GA
19 Apr	SME Fundamentals of Induction Heating Clinic	Nashville, TN
19–22 Apr	53rd Society for Machining Failure Prevention Technology	Virginia Beach, VA
20–21 Apr	SME Induction Heating Technology and Applications Clinic	Nashville, TN
26–29 Apr	NDIA/DoD Logistics Symposium and Exhibition	Tampa, FL
3–5 May	AIAA Global Air & Space ’99 Expo	Washington, D.C.
3–6 May	2nd NDIA Joint Classified Ballistics Symposium	Monterey, CA
4–5 May	ARL Materials and Manufacturing Advisory Board Meeting	State College, PA
6 May	INFAC Annual Industry Briefing	Chicago, IL
12–14 May	JDMT Sustainment Group Meeting	State College, PA
22–23 May	iMAST Quarterly Program Review	State College, PA
23–26 May	13th Annual NCMS Technical Conference and Expo	Orlando, FL
25–27 May	AHS Forum 55	Montreal, Canada
3–4 Jun	NCEMT Johnstown Showcase for Commerce	Johnstown, PA
13–17 Jun	NDIA 5th Annual Joint Aerospace Weapons Support Expo	San Diego, CA
13–15 Sep	4th Annual Conference of Spray Forming	Baltimore, MD
20–23 Sep	Marine Corps League Modern Day Marine Expo	Quantico, VA
21–22 Sep	NCEMT Modern Shipbuilding Technologies	Crystal City, VA
17–20 Oct	Penn State/ARO Workshop on Aeroelasticity of Rotorcraft Systems	State College, PA
24–27 Oct	AGMA Gear Expo ’99	Nashville, TN
Nov (TBA)	ARL Materials and Manufacturing Advisory Board Meeting	State College, PA
Nov 15–18	NDIA 3rd Annual DoD Maintenance Conference and Expo	St. Louis, MO
29 Nov–2 Dec	Defense Manufacturing Conference ’99	Miami, FL

“We have to remember that even as wonderful as this leading-edge technology is, it will still depend on great people to drive, fix, and support it, and that's the real strength of our team, the people who make it possible."

— Admiral Jay Johnson, USN Chief of Naval Operations

PENNSTATE

1 8 5 5

Applied Research Laboratory
P.O. Box 30
State College, PA 16804–0030

ADDRESS CORRECTION REQUESTED